

MIX BITUMEN WITH CRUMB RUBBER, DO WE GET RUBBERISED BITUMEN?

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ABSTRACT

As bitumen additive, various forms of rubber which include scrap rubber from motor vehicle tyres (crumb rubber) have been used for many years throughout the world with varying degree of success. This fact has interest to both rubber producers and road engineers in Malaysia, particularly in producing road surfacing bituminous materials with improved durability and stability. In addition, the use of crumb rubber sounds very attractive from the point of view of preservation of the environment.

A full-scale road trial was successfully constructed on Route 2, Section Nos. 340 - 345, in Kuantan, in June 2003.

The objectives of the trial were to compare the performance of dense graded bituminous overlay incorporating crumb rubber modified bitumen in mitigating reflective cracking with a similar overlay using conventional penetration grade 80-100 bitumen.

Based on the performance of the test sections 52 months after construction, there was an indication that the presence of crumb rubber in asphalt mixtures could significantly mitigate the propagation of cracks from underlying layers through relatively thin overlay with relatively fine aggregate gradation. This was shown by considerably less percentage of cracks that was reflected. However, with coarser aggregate gradation and thicker overlay, the crumb rubber does not appear to impart appreciable improvements in resistance to reflective cracking as it was observed that the section with crumb rubber performed only slightly better than the section without crumb rubber after 52 months.

1.0 INTRODUCTION

The use of scrap rubber from motor vehicle tyres as bitumen additive in the road construction industry sounds very attractive from the point of view of preservation of the environment. The disposal of the used tyres poses quite a serious problem in Malaysia and throughout the world as they are virtually indestructible except by burning which again creates another problem in the form of air pollution.

As bitumen additive, various forms of rubber which include scrap rubber from motor vehicle tyres (hereafter is referred to as crumb rubber) have been used for many years throughout the world with varying degree of success. This fact has interest to both rubber producers and road engineers in Malaysia, particularly in producing road surfacing bituminous materials with improved durability and stability.

With this in mind, a Memorandum of Agreement between Lembaga Getah Malaysia (LGM) and Jabatan Kerja Raya Malaysia (JKR) was signed in December 2002 whereby both parties jointly agreed to carry out a joint development project titled "The Use of Crumb Rubber as Bitumen Additive".

As stated in the above Memorandum of Agreement, LGM *inter alia* has the expertise in the development of different forms of rubber for use as bitumen additives in road construction whereas JKR *inter alia* has the expertise in the production and placement of asphalt mixes incorporating various forms of bitumen additive including crumb rubber.

2.0 LITERATURE REVIEW

The concept of adding rubber into bitumen is more than 100 years old. The first attempt was made in 1898 by de Caudenberg who patented a process for manufacturing rubber – bitumen. However, many difficulties were encountered in exploiting the patent and the process lapsed before 1914.

While the rubber industry had been using bitumen to modify rubber for various purposes, no further progress was made in the modification of bitumen by adding rubber until rubber in granular or powder form was developed in 1930. Then, laboratory assessment and some full-scale road trials on rubber-modified bitumen commenced, notably in the Netherlands and Great Britain. It was reported that the trial sections laid in 1936 at Bussum, the Netherlands showed marked improvement, and the rubberised rolled-asphalt surfacing at New Cross, Great Britain was still in good condition in 1959 after 22 years[1].

The concept of using recycled rubber from car and truck tires, typically referred to as crumb rubber, is at least 50 years old. Laboratory and field trials were carried out from the mid 1950s onwards. Experiments showed promising results when crumb rubber - modified binder was used for seal coats and stress-absorbing membranes, but yielded initially mixed results in terms of performance and cost effectiveness when crumb rubber was used as modifier for asphalt paving mixtures.

2.1 Experiences in the United Kingdom

During the period 1953 – 1966, the Road Research Laboratory of the United Kingdom in co-operation with the Natural Rubber Producers' Research Association (NRPRA, Malayan Rubber Fund Board) carried out a research programme to investigate the possibility of improving the performance of road surfacing by incorporating a small proportion of rubber in bituminous binders[1].

In those early days, the forms of rubber which were available for incorporation into the binder were;

- i. Latex. Extract from rubber trees which was concentrated and stabilised in various ways. Available in two forms, evaporated and centrifuged.
- ii. Sheet rubber. Made from coagulated latex.
- iii. Rubber powder. Made either by spray-drying the latex or by hammer-milling lightly vulcanised coagulum to form a crumb. Available in several forms;
 - Pulvatex – an unvulcanised rubber powder containing 40% inert filler.
 - Mealorub – a lightly vulcanised powder containing 96% rubber.
 - Harcrumb – substantially similar to Mealorub. Manufactured in then Malaya.
 - Rodorub – a lightly vulcanised powder containing 75% natural rubber and 25% inert filler.
- iv. Ground tyre-tread. Waste tyres ground into a powder.

In Huntingdonshire, it was reported that bitumen macadam, rubberised by direct addition of about 7% Pulvatex to the asphalt mixes and laid down in 1955, had lasted eight years as compared to a normal life of six years with standard bitumen macadam[2].

In a full-scale experiment on trunk road A6 in Leicestershire in 1963, Szatkowski[3] reported that asphalt mixes containing 4% natural rubber in the form of evaporated latex and with the binder content increased by 1% had exhibited more resistant to reflection cracking than standard mixes.

It was highlighted elsewhere[4] that latex was the most effective form of rubber, followed by unvulcanised rubber powders (eg. Pulvatex). Vulcanised rubber powders (eg. Harcrumb) dispersed more slowly and were less effective due to the breakdown of rubber during dispersion. As such, addition by dry process was not recommended.

In their Technical Bulletin No.9[5], NRPRA highlighted that four forms of natural rubber which were commonly used in the preparation of bituminous binders were centrifuged latex, evaporated latex, lightly vulcanised or unvulcanised rubber powders specially prepared for blending into bitumen (eg. Harcrumb, Rodorub and Pulvatex) and sheet rubber. Rubber powder from scrap sources was then not recommended as it was variable in composition and generally too highly vulcanised to blend into bitumen without prolonged and excessive heating.

2.2 Experiences in Malaysia

In Malaysia, trials using rubberised bitumen were initiated in 1950s when 100 yards of road between Kota Bharu and Kuala Krai was laid with 5% rubber powder. Following that, several other trials were laid in the states of Kedah, Perlis, Kelantan, Johor, Negeri Sembilan and Melaka. Unfortunately, none of these trials was monitored closely and as such no details are available.

Chew and Ting[6] reported a full-scale experiment that was carried out in late 1968 at two sites; KL – Seremban road at mile 17 - 18 and KL – Bentong road at mile 14 $\frac{1}{4}$ - 14 $\frac{1}{2}$. A conventional 80 - 100 penetration grade bitumen was used with 1.5% and 3% natural rubber latex. The trial sections however failed after three years due to rapid increase in traffics. At that point, JKR concluded that there was nothing to be gained by adding rubber into road surfacing.

With the formation of Institut Kerja Raya Malaysia in 1987, a more concerted effort was given by JKR in the research work. Collaboration with Rubber Research Institute of Malaysia (RRIM) was solicited to tap expertise from local rubber researchers. A number of laboratory assessments and field trials were subsequently conducted under the collaborative study as described below.

2.2.1 Laboratory Assessment

RRIM researcher Azemi[7] carried out laboratory assessment on the toughness, elongation at break, tenacity and yield strength of rubberised bitumen samples using an Instron 4206 machine. The samples were prepared using four different forms of rubber namely prevulcanised NR latex, NR latex concentrated, rejected glove crumbs and tyre shavings.

A similar study was carried out earlier by Institut Kerja Raya Malaysia whereby the temperature susceptibility of rubberised bitumen prepared using various forms of rubber was evaluated[8].

In the RRIM's laboratory, Lai and Rouyan[9] investigated on the use of Pyrolysis Gas Chromatography to determine the content of unvulcanised rubber in rubberised bitumen blend.

2.2.2 Field Trials

a. Klang Trial

The first opportunity to construct a full-scale road trial under the collaborative study came in 1988 during the construction of a new dual carriageway in Port Klang. Natural rubber latex at 2% concentration had been proposed for the trial. The plant engaged to manufacture the bituminous materials was a continuous drum mixer. It had no facility for injecting latex directly into the mixing drum, therefore the rubber was preblended with bitumen in the bitumen storage tank prior to mixing. TRRL Road Note 36[12] specified that a propeller type stirrer should be used. However, the plant did not have this facility so the contractor proposed to blend the latex into the bitumen by circulating the binder from one storage tank to another by means of an external circulating pump. This method of blending was not satisfactory as the resulted blend of rubber and latex was not uniform. Nonetheless, some latex which appeared to have blended with the bitumen seemed to have improved the performance of the modified binder in that the aging of the top few millimetres of the surfacing appeared to be less than in the control and the stiffening effect of the rubber additive reduced FWD deflections more than in the control[10] [11].

b. Rembau Trial

In December 1993, another trial was constructed on Route 1, between Rembau and Tampin. The trial spanned about one kilometre with eight different test sections. Three forms of rubber were used; latex, tyre shaving (or crumb rubber) and rubber powder from rejected domestic gloves. Dry process of mixing was adopted whereby a measured amount of the rubber additives was manually added into the pugmill. Dense graded asphaltic concrete and bituminous macadam, and open graded porous asphalt were laid in the test sections.

Up to May 1997, when the last monitoring was carried out, the control test section showed an average rut depth of 2.3 mm while the rest of the test sections had either zero or negligible rut. All test sections had not cracked then.

Indirect Tensile Strength (IDT) tests carried out on cored samples indicated consistently that rubberised mixes had stiffness modulus higher than the conventional mix.

c. Sg. Buluh Trial

This trial was constructed in December 1996 whereby three kilometres of rubberised mix and one kilometre of conventional mix were constructed. Rubberised bitumen was produced by blending crumb rubber from old tyres passing No. 40 mesh with 80/100 penetration grade bitumen. Detail evaluations were carried out within a 200-metre stretch in each test section.

The only post construction survey reported was carried out in January - March 1997. Except for some localised minor segregation problems found in the control test section, there was no other distress observed then.

Laboratory test results from the trial, however, showed some inconsistent properties. For example, the binder content of the control mix was much lower (4.1%) than the rubberised mix (5.8%) whereas the air voids content was lower in the control mix. There are two possible explanations for this inconsistency; the centrifugal method of binder recovery in accordance to ASTM D 2172 was not accurate enough when rubberised bitumen was involved and the presence of rubber granules in the mix had resisted compaction thereby resulting in relatively high air voids even at relatively high binder contents.

Laboratory dynamic creep tests indicated that the rubberised mix reaches 3% strain faster than the control mix. Based on this observation, it would imply that the rubberised mix had less resistance to permanent deformation. However, the presence of relatively high air voids in the rubberised mix that might contribute to earlier strain development merits a review on this implication.

Both the rubberised and control mixes have relatively low density. The mean density for the control and the rubberised mix was reported to be 2.193 Mg/m³ and 2.154 Mg/m³ respectively compared to typical values in the range 2.30 - 2.35 Mg/m³ for dense graded mix. This could be attributed to inadequate compaction during construction.

d. KLIA Project

The experience mentioned above had led Institute Kerja Raya Malaysia to propose the use of rubberised bitumen in the prestigious KL International Airport project.

Specification Series 900 of the KL International Airport project included the preparation of rubberised bitumen in compliance with TRRL Road Note 36[12] for use in the construction of wearing course of the perimeter road. As recommended by RRIM, high quality grade natural rubber powder with specific vulcanizate properties was specified (refer to page 25 for further details). It did not, however, specifically indicate that crumb rubber from old tyres should be used as the rubber additive.

Superpave performance grade PG70 in compliance with AASHTO MP1 – Standard Specification For Performance Graded Asphalt Binder[13][14] was specified for the rubberised bitumen.

A total length of approximately 50 kilometres of the wearing course of the perimeter road was successfully constructed using rubberised bitumen blend of crumb rubber from old tyres which was tested and certified by LGM. The modified bitumen product, called *Shell Rubberised Bitumen*, which met performance grade PG70 and had been used extensively in the KLIA perimeter road.

e. Other Proprietary Product

Bituminas Premium-R is a proprietary formulation of rubberised bitumen produced and marketed by Petronas. It was claimed that the binder had been used to manufacture dense asphalt mixes for over 15 kilometres of road in Putrajaya as well as access roads and parking areas at the oil and gas plants in Kerteh and Gebeng.

2.3 Experiences in India

India is currently the leading user of crumb rubber for modification of asphalt in Asia. "Guideline Specifications on the Use of Polymer and Rubber Modified Bitumen in Road Construction" were issued by the Indian Roads Congress (IRC) as Special Publication 53 in 1999, and a First Revision of these guidelines was published in 2002. The Bureau of Indian Standards has issued in 2004 Indian Standard IS 14462, which is similar but not identical to IRC Special Publication 53. Both IRC guidelines and IS Standard 14462 include separate specification properties for bitumen modified with natural rubber (NRMB) and for bitumen modified with crumb rubber (CRMB).

Of the three CRMB grades included in IS 14462, CRMB 60 is most appropriate for use on major highways located in hot climate. Comparative testing was carried out on polymer and crumb

rubber modified binders from India, using traditional (Indian) test methods and specifications as well as more advanced test methods and specifications for Performance Graded Binders (AASHTO M 320 and ASTM D 6373). It was found that CRMB 60 is about equivalent to PG 76, which is a widely specified binder grade for heavily trafficked highways in warm to hot climates.

2.4 Experiences in Europe

In Europe, crumb rubber has so far not been as extensively used as asphalt modifier as in the US. However, the European Tire Recycling Association (ETRA) is aggressively promoting environmental and performance benefits of crumb rubber as bitumen additive, and in view of the increasing emphasis on the need for recycling and economic use of recycled materials, crumb rubber usage in asphalt pavement is expected to increase also in Europe.

2.5 Experiences in the United States

Because disposal of used tyres in landfills presents an increasing environmental problem, legislation at federal, state and local government levels in the US started about 20 years ago to promote, and in some cases mandate, the use of crumb rubber (CR) in asphalt pavements. The most notable of these legislations was the Intermodal Surface Transportation Efficiency ACT (ISTEA) passed by the US Congress in 1991. It mandated that starting in 1994, at least 5% of all asphalt mixtures used for federally funded highway projects be modified with CR. The mandate stated further that each of the following years, usage of CR as asphalt modifier was to be increased by 5%; in 1997 and each year thereafter, at least 20% of all federally funded asphalt paving projects should have included CR as modifier. This legislation caused a sharp increase in interest and in use of CR as asphalt modifier. Because many state transportation departments did not have sufficient experience in CR-modified binder and mix design, and in related asphalt mix production and pavement construction, some of the projects carried out during this period did not meet performance expectations. As a result, the federal mandate of using CR in asphalt pavements was suspended in the Transportation Appropriations Bill of 1995 and funds were set aside to conduct more research on;

- a. Test methods and specifications for CR modified asphalt binders and mixtures.
- b. Performance properties of asphalt binders and mixtures containing CR.
- c. Asphalt mix design using CRMB as binder.
- d. Asphalt mix production and pavement construction using CRMB.
- e. Project quality control and quality assurance.

US is not only the primary contributor to CR technology development, but is currently also the largest user of CR in asphalt pavements. Until 1992, more than 6 million tonnes of asphalt mix modified with CR was produced and used in pavement construction; since then, usage has been growing, especially in Florida, California, Texas and Georgia, and has now reached in the US more than 15 million tonnes of CR-modified asphalt mixes per year. Most of the CR-modified binder is used in gap-graded mixtures, such as porous asphalt and open-graded friction course. The percentage of CR in bituminous binder used for friction course is typically in the range of 12 to 16%; higher CR dosages are typically used in Arizona. For dense graded asphalt mixtures, low CR dosages are used, ranging from about 5% in Florida to approximately 8% in some other states.

The performance of crumb rubber modified asphalt mixes in the US in 1970s and 1980s are summarised in Table 1 below (extracted from an unknown source).

It was also reported that the Texas Transportation Institute (TTI) has carried out a comprehensive study on dense-graded mixes which TTI claimed that the addition of crumb rubber does not improve the properties of the mixes (source unknown, extracted from LGM's literature review).

Table 1. United States experiences in crumb rubber.

| STATE | | REMARKS |
|-------|--------------|---|
| 1 | Alaska | Pavement sections placed in 1979 – 1983 using dry process (refer to Note below) have superior fatigue resistance but were not as good as conventional in resisting ravelling and pothole formation. |
| 2 | Arizona | The longest user of crumb rubber modified mixes, Arizona presently uses dense and open-graded mixes made with asphalt-rubber binders for overlays on existing rigid and flexible pavements. |
| 3 | California | After using crumb rubber for more than 20 years, California recommends; i. Asphalt-rubber open-graded mixes should no longer be considered as an experimental technology. ii. Asphalt-rubber dense and gap-graded mixes should be used on an experimental basis. iii. Dry process using devulcanised rubber should not be used. |
| 4 | Connecticut | Based on nine-year performance study of asphalt-rubber pavement produced using dry process, Connecticut concludes; i. On thick overlays, 2% crumb rubber increase reflection cracking as compared with control sections. ii. On thin overlays, 1% crumb rubber reduce reflection cracking by two-third. Increased in crumb rubber contents result in more cracking. |
| 5 | Florida | All asphalt-rubber dense and open-graded sections performed well since 1989-1990. Beginning in January 1994, all dense and open-graded friction courses require an asphalt-rubber binder. |
| 6 | Kansas | Two experimental asphalt-rubber dense-graded sections placed in 1990 showed more reflection cracking. |
| 7 | Michigan | Eight experimental sections constructed in 1978-1979 performed poorly in terms of reflection cracking and surface disintegration cracking. Michigan does not recommend the use of crumb rubber modified asphalt. |
| 8 | Minnesota | Three experimental sections did not show benefits which offset costs. No future sections were planned until more specific benefits were identified. |
| 9 | Mississippi | A test section with 6% devulcanised rubber showed little significant difference in crack pattern, skid resistance and rutting after 2 years as compared with the control section. |
| 10 | Oregon | After 5 years, rubber modified section showed better resistance to cracking. However, ravelling in the section was of concern. |
| 11 | South Dakota | Dry process rubber modified sections developed some potholes and break-up after 1 year which subsequently developed into large areas of delamination and peeling. |
| 12 | Texas | Of two sections, one ravelled shortly after construction while the other performed satisfactorily. |
| 13 | Utah | Dry process rubber modified section was removed after 3 years because of severe ravelling. |
| 14 | Washington | Five open-graded sections showed good to very good performance. Dry process sections showed poor to average performance. |

3.0 QUALITY OF TYPICAL CRUMB RUBBER IN MALAYSIA

Crumb rubber for use in the laboratory assessments and subsequent field trials in Kuantan was obtained from Jeng Yuan Reclaimed Rubber Sdn. Bhd. This company was established in 1988 with the principal activity in manufacturing and sale of premium quality reclaimed rubber.

During a visit to the factory in Port Klang by JKR and LGM officials in March 2003, it was briefed that its monthly output then was 600 metric tons, 50% of which was exported to countries like Taiwan, Japan, Vietnam, India and Australia. Crumb rubber of mesh 40 (420 μm) appeared to be a major product with a monthly output of approximately 500 metric tons. It was used mainly in the manufacture of moulded rubber products. Finer crumb of mesh 80 (180 μm) was produced in much lesser quantity of 12 metric tons per month as the factory did not have facilities to purposely produce the finer crumb which was mainly used in making shoe soles.

The source for the crumb rubber was rubber buffings and dust which were purchased at 40 sen/kg from various tyre retreading companies. The type of tyre that was retreaded was mainly truck tyres which contain higher proportion of natural rubber as compared to passenger car tyres which are generally made of Styrene-Butadiene synthetic rubber (SBR) or polybutadiene synthetic rubber. The crumb rubber of mesh 40 was then priced at 80 sen/kg.

The typical quality of crumb rubber produced by Jeng Yuan as compared to the Caltrans specification is shown in Table 2 below.

Table 2: Chemical composition of Jeng Yuan crumb rubber.

| Test Parameter | Caltrans Crumb Rubber | Jeng Yuan Crumb Rubber |
|------------------------|-----------------------|------------------------|
| Acetone Extract (%) | 6 – 16 | 10.9 |
| Rubber Hydrocarbon (%) | 42 – 65 | 57.0 |
| Carbon Black (%) | 28 – 38 | 28.3 |
| Natural Rubber (%) | 22 – 39 | n.a. |
| Ash (%) | < 8.0 | 3.7 |

4.0 FULL-SCALE ROAD TRIAL IN KUANTAN

4.1 Objectives

The objectives of the trial were to compare the performance of dense graded bituminous overlay incorporating crumb rubber modified bitumen with a similar overlay but using conventional penetration grade 80-100 bitumen in mitigating reflective cracking and to assess the durability of porous asphalt incorporating crumb rubber modified bitumen as well as a proprietary modified bitumen produced by Petronas.

4.2 Site selection

A site on Route 2, between Section No. 340 and 345, Kuantan bound was proposed by JKR District of Kuantan. The road pavement of the four-lane dual carriageway which was constructed in early 1990s has visibly reached a critical or fail condition over a substantial proportion of its length and rehabilitation was then urgently required. In fact it had been identified by the JKR District of Kuantan to be overlaid by the Federal Road maintenance concessionaire, Road Care Sdn. Bhd. The proposed site was therefore needed to be truncated from the maintenance contract in order to facilitate the construction of the test sections.

4.3 Experimental Design

As the incorporation of crumb rubber modified bitumen, as reported elsewhere, can extend the design life for any given overlay thickness, it can also be used to reduce the thickness of overlay of a given design life. However this design approach was not adopted, instead overlay of similar thickness was placed for each type of aggregate gradation used, with or without crumb rubber. The test site was divided into seven test sections as follows;

- Dense-graded asphaltic concrete, aggregate grading A, with crumb rubber modified bitumen (hereby referred to as R-Dense A), 40 mm thick.
- Dense-graded asphaltic concrete, aggregate grading A, with conventional penetration grade 80-100 bitumen (Dense A), 40 mm thick.
- Dense-graded asphaltic concrete, relatively fine aggregate grading B, with conventional penetration grade 80-100 bitumen (Dense B), 30 mm thick.
- Dense-graded asphaltic concrete, relatively fine aggregate grading B, with crumb rubber modified bitumen (R-Dense B), 30 mm thick.
- Open-graded porous asphalt, aggregate grading C, with crumb rubber modified bitumen (R-Porous C), 40 mm thick.

- vi. Open-graded porous asphalt, aggregate grading C with Petronas modified bitumen (Petronas-Porous C), 40 mm thick.
- vii. Open-graded porous asphalt, relatively fine aggregate grading D, with crumb rubber modified bitumen (R-Porous D), 40 mm thick.

Dense B and R-Dense B were to be laid to 30 mm thickness because the maximum nominal size of the aggregate was only 10 mm and pavement surface cracks were expected to appear faster than in the 40 mm thick overlay.

4.4 Determination of optimum crumb rubber content

Crumb rubber-bitumen blends with variable content of crumb rubber (CR) were prepared in the laboratory. The quantity of CR added ranged from 0% to 16% at an increment of 4%, by weight of the bitumen.

4.5 Dynamic Shear Rheometer testing

Dynamic Shear Rheometer (DSR) is used to characterize the viscous and elastic behaviour of the bitumen. It does this by measuring the complex shear modulus G^* and phase angle δ of the bitumen. G^* is a measure of the total resistance of the bitumen to deform when repeatedly sheared and it consists of two parts; elastic (recoverable) and viscous (non-recoverable). δ is an indication of the relative amount of recoverable and non-recoverable deformation.

Non-recoverable or permanent deformation is controlled by limiting $G^*/\sin \delta$ at any test temperature to value greater than 1.0 kPa for fresh or unaged bitumen and 2.2 kPa after aging in Thin Rolling Film Oven Test (RTFOT) or Rolling Thin Film Oven Test (TFOT).

It is this DSR test that was used to determine the optimum content of crumb rubber in the modified binder. Binder grade PG 76 has been specified for the crumb rubber modified binder. As such, samples of the laboratory blend of crumb rubber-bitumen were subjected to DSR test at 76°C. TFOT was used for aging the binders. The tests were carried out at University Malaya.

Referring to Figure 1, $G^*/\sin \delta$ of unaged sample equals to 1.0 kPa at crumb rubber content of about 12% whereas Figure 2 indicates that $G^*/\sin \delta$ of TFOT-aged sample reaches 2.2 kPa at rubber crumb content of about 17%. The results show that $G^*/\sin \delta$ increases exponentially with increasing crumb rubber content for both unaged and TFOT-aged samples. It was jointly decided by JKR and LGM that crumb rubber content of 16% be used in the road trial in Kuantan.

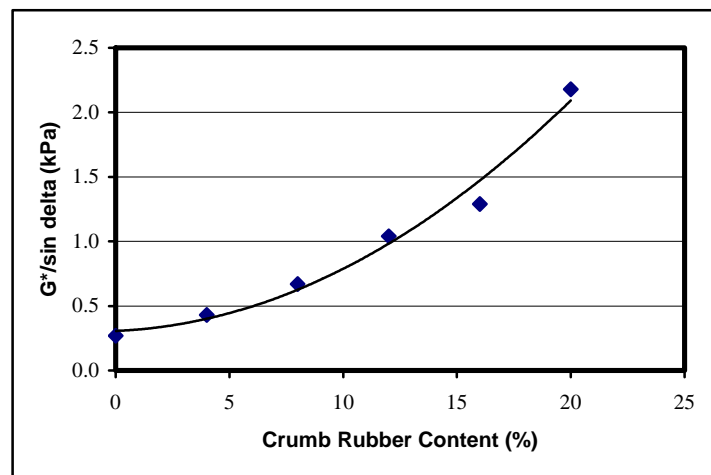


Figure 1. Variation of $G^*/\sin \delta$ with crumb rubber content for unaged binder.

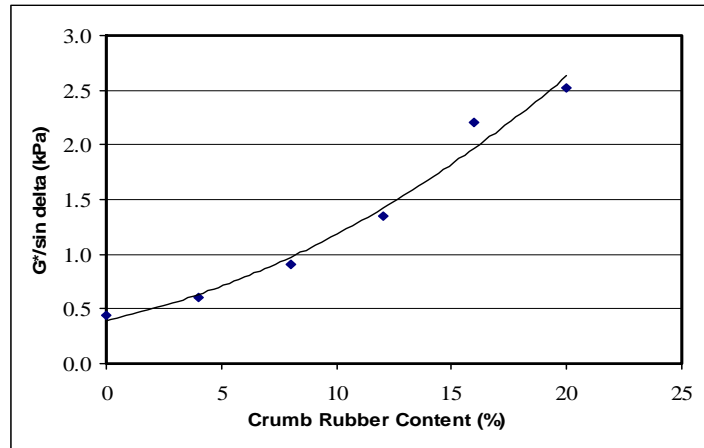


Figure 2. Variation of $G^*/\sin \delta$ with crumb rubber content for TFOT- aged binder.

The blend with 16% CR content was subsequently used in the preparation of dense-graded (grading A & B) and open-graded (grading C & D) mixtures at varying binder contents ranging from 4.5% to 7.5%.

4.6 Construction

The construction of the trial commenced on 13th June 2003 beginning from test point -10 on the slow lane. As monitoring of the test sections would be confined to the slow lane only, supervision of the construction was carried out on this lane only. The construction of all seven test sections on the slow lane was completed on 30th June 2003.

5.0 DISCUSSION

The full-scale road trial in Kuantan provided an opportunity to evaluate the performance of crumb rubber modified bituminous overlay in mitigating reflective cracking, the most widely reported benefit of using crumb rubber as bitumen modifier. The presence of crumb rubber in the bitumen improves significantly the binder resistance to oxidative aging. Some components of crumb rubber have lower activation energy than bitumen, while other components act as anti-oxidant. The components with low activation energy react more rapidly with oxygen than bitumen. This influences positively the aging behaviour of the modified binder, because the product of rubber-oxygen reaction is less detrimental to the binder and mixture performance than is the product of bitumen-oxygen reaction. Overall hardening of the binder is, therefore, slowed down significantly by the presence of crumb rubber. The effect of aging is further reduced by the presence of carbon black, which is an anti-oxidant, and by the typically thicker binder films of crumb rubber-modified asphalt mixtures. Despite its being more viscous and higher stiffness, failure strain of properly formulated and produced crumb rubber modified binder is larger than that of conventional bitumen, thus increasing also resistance to crack initiation and propagation.

With extensive cracking in the underlying layer, high traffic loading and relatively thin cosmetic overlay (40 mm), it was anticipated that the cracks would propagate into the new overlay within a relatively short period of time. Even a thinner overlay (30 mm) was included in the test sections in order to expedite further the impending appearance of reflection cracks on the surface of the new overlay so that the comparison of performance between the test sections with and without crumb rubber could be made after a shorter period of time.

The approach adopted in the design of thickness of the new overlay was that a similar thickness was specified for both test sections with and without crumb rubber rather than reducing the thickness of the overlay modified with crumb rubber accordingly such that a design life similar to the overlay without crumb rubber was achieved.

With the possibility of thicker film of binder having improved resistance to oxidative aging, the crumb rubber modified binder was also used in the construction of porous asphalt test sections.

The other benefit that is normally associated with the use of crumb rubber as bitumen modifier is improved resistance to rutting of overlay due to the presence of the more viscous modified binder. However, as the test sections were located on a relatively flat terrain, the overlay was not expected to be subjected to high traffic loads at extremely long loading times which would be normally associated with slow moving heavy commercial vehicles. Under such extreme conditions, the binder would behave in a more viscous manner, allowing the bituminous mixture to flow under the high traffic stresses. The progression of surface deformation along the wheelpaths was therefore not monitored in this trial.

Periodic monitoring on the formation of surface cracks in the dense mixture test sections and ravelling in the porous asphalt test sections was carried out by manual observation and this was confined to the slow lane only where most of the heavy vehicles would be travelling on.

The presence of cracking and ravelling were recorded as percentage of the total area within each test section. **Table 3** below shows these results for all the test sections which were obtained at various time intervals after construction.

Table 3. Field monitoring test results.

| Mix Types | Time After Construction (months) | | | | | | | | % of Initial Cracked Area at Month 52 |
|------------|----------------------------------|-----|-----|-----|-----|-----|-----|------|---------------------------------------|
| | Percentage Area of Cracking | | | | | | | | |
| | Initial (before constr.) | 0.5 | 3 | 6 | 12 | 18 | 30 | 52 | |
| R-Dense A | 52.5 | 0 | 0 | 0 | 0 | 2.8 | 5.8 | 6.0 | 11.4 |
| Dense A | 44.8 | 4.5 | 4.5 | 4.5 | 5.0 | 5.0 | 7.0 | 7.2 | 16.1 |
| Dense B | 14.3 | 5.0 | 5.0 | 5.0 | 6.0 | 6.0 | 8.0 | 12.0 | 83.9 |
| R-Dense B | 12.0 | 0 | 0 | 0 | 0 | 0.8 | 2.0 | 3.2 | 26.7 |
| | Percentage Area of Ravelling | | | | | | | | |
| R-Porous C | 3.0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| R-Porous D | 1.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| P-Porous C | 1.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

There is an indication that the presence of crumb rubber in asphalt mixtures could significantly mitigate the propagation of cracks from underlying layers through relatively thin overlay with relatively fine aggregate gradation. This was shown by considerably less percentage of cracks that was reflected. However, with coarser aggregate gradation and thicker overlay, the crumb rubber does not appear to impart appreciable improvements in resistance to reflective cracking as it was observed that both sections with and without crumb rubber were performing equally well after 52 months of monitoring. The extra cost incurred by the addition of crumb rubber to the road surfacing material would not be justifiable if significant improvements could not be attained. Further monitoring of the test sections is recommended to ascertain that appreciable improvements as in the thin overlay could be achieved in the thicker overlay after a longer time period.

It was also observed that there was no ravelling in all three porous asphalt test sections. This could be attributed to the relatively thick film of binder coating the aggregates due to the presence of crumb rubber in the R - Porous C and R - Porous D test sections and proprietary additive in the Petronas - Porous C test section.

6.0 CONCLUSIONS

- The presence of crumb rubber in the road surfacing dense material appear to impart appreciable improvements on resistance to reflective cracking in relatively thin overlay with relatively fine aggregate gradation. However, similar improvements could not be ascertained in thicker overlay with coarser aggregate gradation as it was observed that the section with crumb rubber performed only slightly better than the section without crumb rubber after 52 months.
- With properly designed dense graded asphalt mixture using coarser Superpave aggregate gradation, the overlay appears to have the ability to resist reflective cracking even without crumb rubber additive.

- iii. There was no ravelling in all three porous asphalt test sections. This could be attributed to the relatively thick film of binder coating the aggregates and improved resistance to oxidative aging of the binder due to the presence of crumb rubber in the R - Porous C and R - Porous D test sections and proprietary additive in the Petronas - Porous C test section.
- iv. The addition of 16% crumb rubber to penetration grade 80-100 bitumen reduces the penetration value by 2 grades. However, the softening point merely increases marginally from a normal range of 45 - 52 °C to 56 °C.
- v. The ductility is significantly reduced from over 100 cm, a requirement for penetration grade 80-100 bitumen, to about 27 cm with an addition of 16% crumb rubber.
- vi. PG 76 binder could be achieved by adding 16% crumb rubber from truck tyre buffing to penetration grade 80-100 bitumen.
- vii. The crumb rubber obtained locally from Jeng Yuan Reclaimed Rubber Sdn. Bhd. in Port Klang which was produced by grinding rubber buffing from truck tyres did comply with California Department of Transports specification for chemical composition of crumb rubber.

7.0 RECOMMENDATIONS

- i. LGM should proceed in developing better forms of rubber for use as bitumen additive, whether it is to be applied in the dense-graded or open-graded asphalt, as crumb rubber from rubber buffing of truck tyres would not be a good proposition and would definitely not resolve the problem in disposing the abundant used car tyres in this country. If natural rubber latex could be developed by LGM as cost-effective bitumen additive, it is envisaged that the impact to the Malaysia rubber industry would be more pronounced.
- ii. The rubber modified binder and asphalt mixes should be subjected to laboratory testing such binder elastic recovery, indirect tensile fatigue and resilient modulus for some indications of improved resistance to reflective and surface cracking of dense-graded asphalt mixes prior to trial application on the roads.
- iii. Crumb rubber modified binder in dense asphalt mixtures should be equivalent to Type II asphalt rubber as specified in California. This blend should contain 75% rubber from scrap tyres and 25% rubber from high natural rubber resources.
- iv. The scrap tyres should consist of ground rubber derived from tyre buffing of truck tyres whereas the high natural rubber should be ground rubber derived from materials that utilise high natural rubber resources.
- v. Based on California Department of Transports, the properties of the rubber from scrap tyres and high natural rubber resources should be as follow;

| Test parameter | Crumb Rubber | High Natural Rubber |
|------------------------|--------------|---------------------|
| Acetone Extract (%) | 6.0 – 16 | 4.0 – 16 |
| Rubber Hydrocarbon (%) | 42 – 65 | < 50 |
| Carbon Black (%) | 28 – 38 | - |
| Natural Rubber (%) | 22 – 39 | 40 – 48 |
| Ash (%) | < 8.0 | - |

- vi. Performance graded binder should be used as a basis for specification of the crumb rubber modified bitumen.
- vii. PG 76 should be the target for crumb rubber modified bitumen formulation and production for use in either dense or open graded asphalt mixtures.

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